

High-Dose Radiation Health Effects Studies

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High-Dose Effects Data

High-dose radiation exposure data from studies of

- ▶ Radium dial painters
- ▶ Atomic bomb survivors
- ▶ Chernobyl first-responders
- ▶ Goiania, Brazil radiological accident victims and survivors

A vertical photograph showing a person's hand holding a metal pot over a stove. The background is dark, and the pot is illuminated. The image is overlaid with a blue geometric pattern consisting of various shades of blue triangles and polygons.



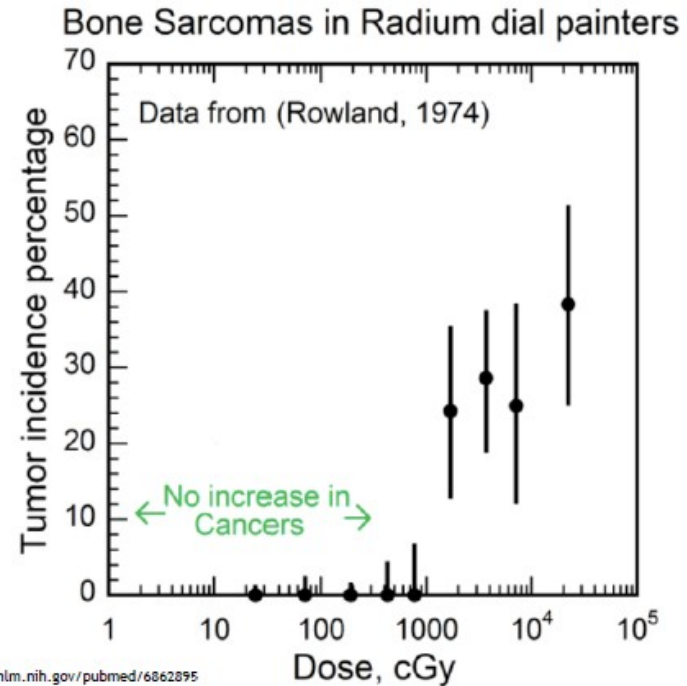
Radium Dial Painters (cont.)

- ▶ Ingestion of Ra-226 accumulated in bones (Ra-226 biological half-life of 43.8 years)
- ▶ 64 bone sarcomas in 264 dial painters with more than 100 microcuries (μCi) of Ra-226 intake; no sarcomas in 2119 painters with $<100 \mu\text{Ci}$ intake
- ▶ 30-year follow-up of 1155 dial painters with intakes $<100 \mu\text{Ci}$ showed lower cancer incidence than general population and longer life span^a
- ▶ Established Ra-226 intake activity threshold of $100 \mu\text{Ci}$ for increased cancer risk (absorbed dose threshold about 10 Gy)

Radium Dial Painters (cont.)



http://journals.lww.com/health-physics/Abstract/1974/11000/Radium_in_Man_10.aspx



<http://www.ncbi.nlm.nih.gov/pubmed/6862895>

Definite threshold for radiation-induced cancer risk at 1000 cGy

Atomic Bomb Survivors



Atomic Bomb Survivors

- ▶ Life Span Study (LSS) estimated acute plus chronic whole-body exposures
- ▶ Reconstructed dose data for about 11,300 survivors receiving high radiation exposures (>200 mGy)
- ▶ While dose estimates subject to uncertainty, **single most important source of data for evaluating risks of low LET radiation at low and moderate doses**
- ▶ Cancer is main latent effect addressed in survivor studies
 - Increased cancer risk for high doses (>200 mGy)
 - Decreased cancer mortality rate and longer life expectancy for doses <200 mGy compared to unexposed population^a

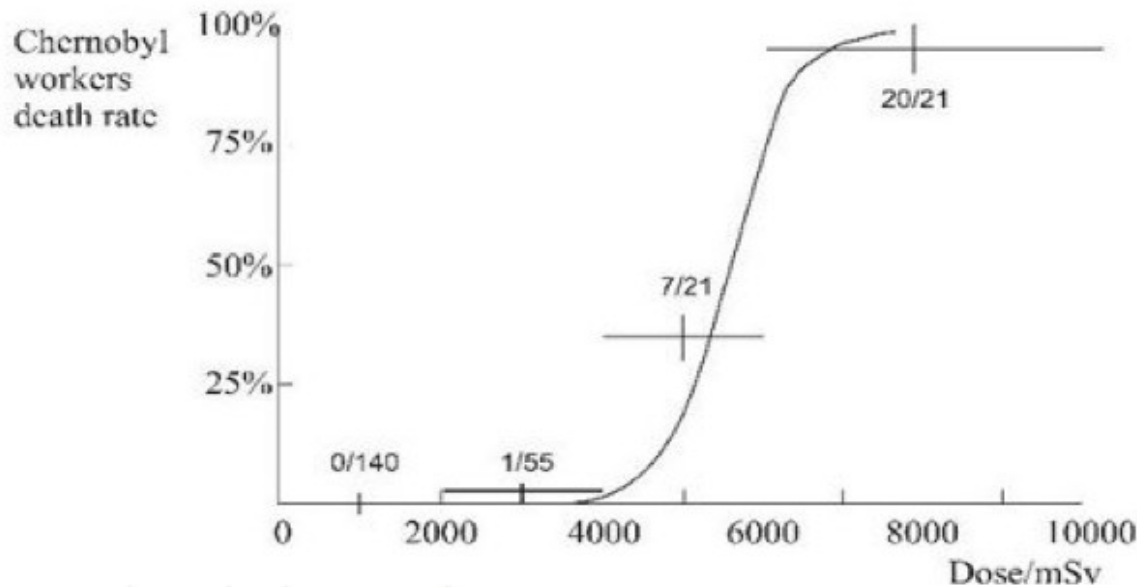
Chernobyl First Responders



Chernobyl First Responders (cont.)

- ▶ External whole-body acute exposures to gamma-rays
- ▶ 97 experienced acute radiation syndrome (ARS); 28 died, 22 of 69 who recovered died of various causes in following 19 years
- ▶ None of 140 responders exposed to less than 2,000 mSv (i.e., high doses) died from radiation-induced causes
- ▶ Data supports ARS threshold dose of 2 Sv (2 Gy)

Chernobyl First Responders (cont.)



Above 4,000 mSv (400 rem)
27 of 42 exposed workers died

Below 2,000 mSv (200 rem)
none of 140 exposed workers died

Source: Wade Allison, Radiation and Reason

The Radiological Accident in Goiânia



INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1988

Goiania Radiological Accident

Unique radiological incident in that casualties incurred initial acute whole-body external irradiation followed by chronic (18 day) whole-body internal exposure at low dose-rate from ingested Cs-137 (biological half-life of 70 days)

- ▶ Some individuals incurred multiple acute external exposures over period of 18 days
- ▶ 8 people experienced ARS; 4 died
- ▶ Of 249 people with external contamination (129 also having ingested Cs-137), 20 required hospital treatment
- ▶ 21 people exposed to high radiation doses greater than 1 Gy did not experience radiation sickness and did not incur cancer in following 25 years

Internal Radiation Dose Effects

Whole body internal radioactivity, kBq			Number of people	Dose mGy per month	Mortality
Goiania	Cs-137	above 1,000,000 kBq	1	above 6,500	ARS
Litvinenko [10]	Po-210	100,000-300,000 kBq	1		ARS
Goiania	Cs-137	100,000-1,000,000 kBq	7	650-6,500	50% ARS
Dial painters [11]	Ra-226	3,700 kBq threshold	264	more than 120	64
Goiania	Cs-137	10,000-100,000 kBq	20	65-650	nil
Goiania	Cs-137	1,000-10,000 kBq	23	6.5-65	nil
Goiania	Cs-137	100-1,000 kBq	15	0.65-6.5	nil
Goiania	Cs-137	10-100 kBq	11	0.065-0.65	nil
Fukushima adults [9]	Cs-137	all below 12 kBq	32,811	all below 0.07	
Normal body [12]	K-40	4.4 kBq	all	0.025	
Fukushima children [9]	Cs-137	all below 1.4 kBq Nov 2011- Feb 2012	1,494	all below 0.01	

ARS = acute radiation syndrome
 $1 \text{ kBq} = 2.7 \times 10^{-2} \text{ } \mu\text{Curie}$

Decay modes:
 Cs-137 - β/γ
 Po-210 - α/γ
 Ra-226 - α/γ
 K-40 - β/γ

Internal Dose Effects Table Notes

- ▶ Internal doses shown in table are whole-body absorbed doses from ingestion of indicated radionuclides
 - Dose per month meaningless unit for both acute and chronic radiation exposures (acute exposures are short duration, chronic low-dose exposures not cumulative)
- ▶ Litvinenko dose from acute exposure to alpha radiation from ingested polonium-210 (50-day biological half-life)
- ▶ Radium dial painter deaths from chronic exposure to alpha radiation from years of Ra-226 accumulation in bones

Internal Dose Effects Notes (cont.)

- ▶ Fukushima and “Normal body” doses from chronic exposure to low-dose beta and gamma radiation
 - “Normal body” exposure received by humans from normal body burden of potassium-40 (everywhere in our environment)
 - Fukushima entries show small releases of cesium-137 from damaged Fukushima nuclear reactors in 2011 resulted in internal doses to local Japanese population similar to what all humans receive from potassium-40 in our bodies
- ▶ Goiania doses less than ARS threshold (2 Gy) from chronic exposure to beta and gamma radiation

High-Dose Effects Threshold

High-dose acute exposure threshold for harm of 200 mGy consistent with high-dose effects study data

Health Effects vs Dose Range

Dose Range 1 Effects

Dose: 0-10 rem (0-100 mSv)

Acute/Chronic Dose Response: No observable detrimental health effects

Acute doses (medical diagnostic procedures)

- 0.01 rem (0.1 mSv) – full-mouth dental x-rays, chest x-ray
- 0.1 rem (1 mSv) – spinal/pelvic/hip x-ray, mammogram
- 0.5 rem (5 mSv) – kidney/spinal series x-rays, barium-related x-rays, head CT scan, most nuclear medicine brain, liver, kidney, bone, or lung scans
- 1 rem (10 mSv) – barium enema (large intestine) x-rays, chest/abdomen/pelvic CT scans
- 5 rem (50 mSv) – heart x-rays

Chronic dose – natural background radiation

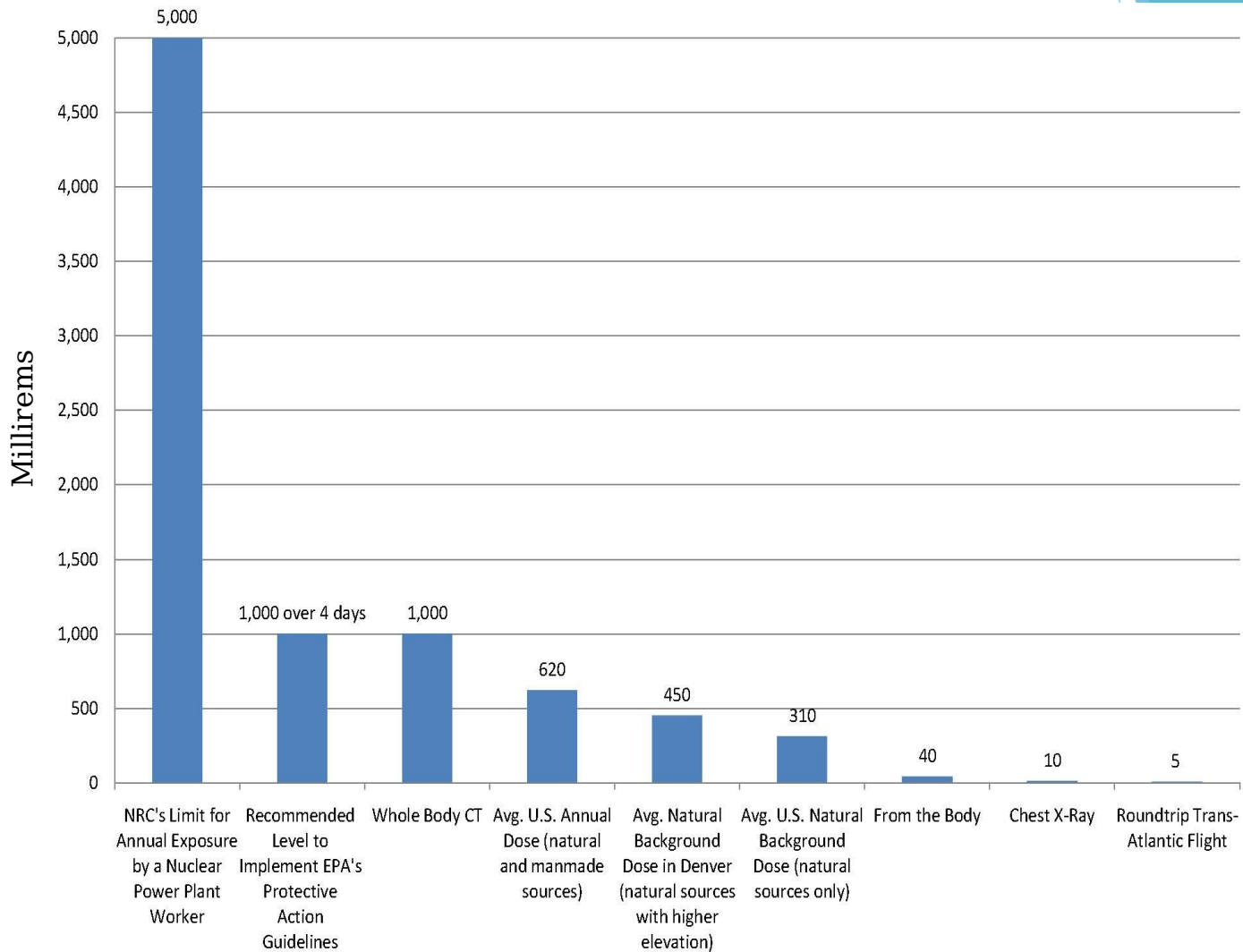
Dose Range 1 Effects (cont.)

Position statement of Health Physics Society*

- Radiogenic health effects (primarily cancer) demonstrated through epidemiological studies
only at acute doses exceeding 100 mSv
- Estimation of adverse health effects below (acute) dose of 100 mSv remains speculative
- Epidemiological studies have not demonstrated
adverse health effects for doses less than 100

Dose Range 1

Examples



Dose Ranges 2 and 3 Effects

Range 2 Dose: 10-50 rem (100-500 mSv)

Acute Dose Response:

- Short-term blood cell decreases for ≈ 30 rem doses
- No valid epidemiologic or experimental data to support linearly extrapolated predictions of cancer from higher dose cancer data
- 20 rem is reasonable acute high dose threshold (i.e., NOAEL)

Chronic Dose Response:

- Chronic doses in high background radiation areas of world (< 30 rem/yr) exhibit no adverse biological effects

Range 3 Dose: 50-100 rem (0.5–1 Sv)

Acute Dose Response:

- Nausea and fatigue
- Delayed effects – slightly increased cancer risk

Dose Range 4 Effects

Dose: 100-300 rem (1-3 Sv)

Acute Dose Response:

- Radiation sickness (nausea, vomiting, diarrhea, reduced lymphocyte cell count) within ≈ 48 hours
- Destruction of blood, GI tract, reproductive, and hair cells; DNA/RNA damage in surviving cells
- Delayed (long-term) effects
 - Leukemia/lymphoma/cancer
 - Cataracts
 - Genetic defects
 - Blood disorders
 - Lifespan shortening

Dose Ranges 5 and 6 Effects

Range 5 Dose: 300-500 rem (3-5 Sv)

Acute Dose Response:

- Radiation sickness occurs within hours
- Loss of hair and appetite occurs within a week
- Statistically, half of exposed population will die without medical attention

Range 6 Dose: 500-1200 rem (5-12 Sv)

Acute Dose Response: Death within a few days

- 1,000 rem (10 Sv) given over several days in fractionated doses to destroy bone marrow in preparation for marrow transplant
- 1,000 rem in fractionated doses used to kill tumors

Supplemental Slides

Japanese Atomic Bomb Survivors

- Life Span Study (LSS) investigated long-term effects of A-bomb radiation on causes of death and incidence of cancer based on epidemiologic (cohort and case-control) studies
- About 120,000 subjects selected from residents of Hiroshima and Nagasaki, including 94,000 atomic bomb survivors and 27,000 unexposed individuals
 - Acute (initial) radiation exposure estimates based on radiation emitted from fireball (prompt gamma and neutron radiation)
 - Chronic exposure estimates based on residual radiation

Japanese Atomic Bomb Survivors (cont.)

Estimated Dose (mGy)		No. of Subjects
Dose Known		86,720
	<5	45.0%
	5-99	34.2%
	100-499	14.3%
	500-999	3.9%
	1,000-1,999	1.9%
	$\geq 2,000$	0.6%
Dose Unknown		7,021
Not in city cohort		26,580
Total		120,321

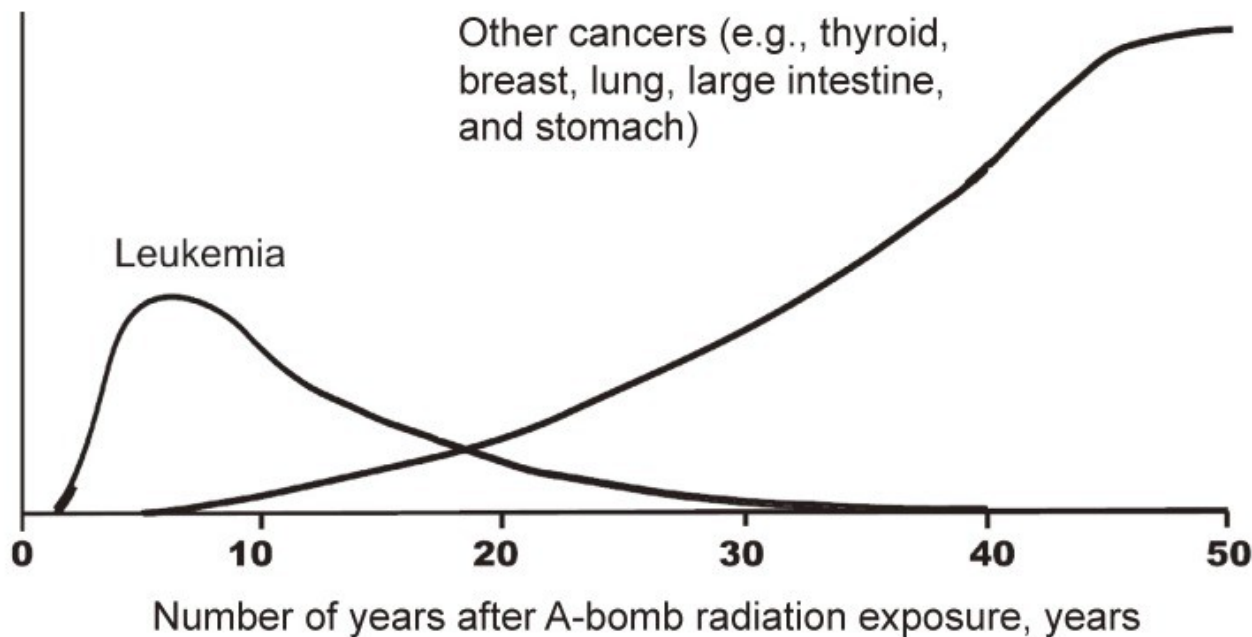
Distribution of LSS subjects by radiation dose

Japanese Atomic Bomb Survivors (cont.)

Weighted colon dose (Gy)	LSS subjects	Cancers		Attributable risk (%)
		Observed	Estimated excess	
0.005–0.1	27,789	4406	81	1.8
0.1–0.2	5,527	968	75	7.6
0.2–0.5	5,935	1144	179	15.7
0.5–1.0	3,173	688	206	29.5
1.0–2.0	1,647	460	196	44.2
>2.0	564	185	111	61.0
Total	44,635	7851	848	10.7

Observed and estimated excess radiation-induced solid cancers in exposed group^a (through 1997)

Japanese Atomic Bomb Survivors (cont.)

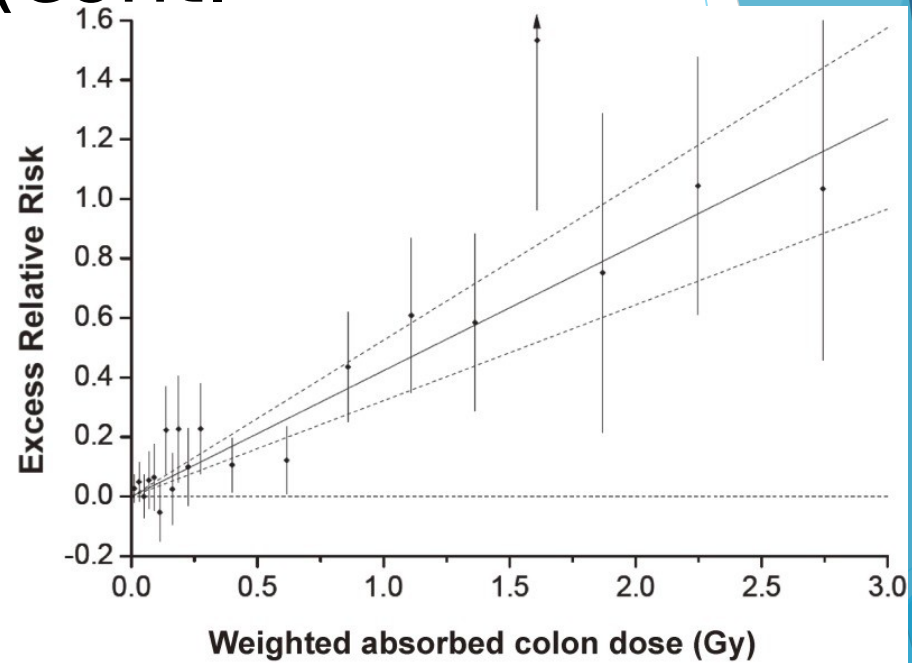


Trend of
Excess
Cases
of
Leukem
ia and
Cancer

Japanese Atomic Bomb Survivors (cont.)

Typical LSS dose-response plot (ERR)^a

- ▶ 22% risk of death at 1 Gy^b
- ▶ 47% risk of solid cancer incidence at 1 Gy^b



High-Dose Radiation Exposures

Single acute dose above top horizontal line; repeated doses below. Belarus/Ukraine kids: thyroid dose

Group	Size	Period	Cumulative dose mSv	Dose rate mSv/day	Result
Atom bomb survivors					
Leuk 5-150[23]	33,459	seconds	5 to 150	5 to 150	Insignificant decrease in leukemia
Solid 5-20[19]	14,555	seconds	5 to 20	5 to 20	Insignificant decrease in solid cancers.
Solid 20-40[19]	6,411	seconds	20 to 40	20 to 40	Solid cancers same as control
Solid 40-125[19]	10,970	seconds	40 to 125	40 to 125	Insignificant increase in solid cancers.
Leuk 150-300[23]	5,463	seconds	150 to 300	150 - 300	Insignificant increase in leukemia.
Solid 125+[19]	16,166	seconds	125+	125+	Significant increase in solid cancers.
Leuk 300+[23]	6,793	seconds	300-5000+	300-5000+	Significant increase in leukemia.
Goiania[10]	≈46	hrs or less	1000-6000	1000-6000	50% mortality abv 4000 mSv
Thai scrap[11]	≈10	hrs or less	1000-6000	1000-6000	100% mortality abv 6000 mSv
Chern firemen+[24]	134	<2 hrs	1000-16000	1000-16000	Sigmoid mortality, 50% mortality at 6000 mSv.
H. Daghlia[14]	1	seconds	5900	5900	Died in 25 days
Tokaimura[14]	3	seconds	3000-17000	3000-17000	>10,000 mSv died
Louis Slotin[14]	1	seconds	21000	21000	Died in 9 days
Norway tech[6]	1	< hour	38500	38500	Died in 13 days
R. Peabody[14]	1	seconds	>100000	100000+	Died in 2 days
Chernobyl liquid-ators[12]	220,000	2 min to 90 days	1-1500	nil to 1500 most < 2	Low/high dose rate mushed together. 6% increase in cancer. Decrease in mortality.
Litvinenko[5]	1	3 weeks	96,000	4,000	Died in 23 days
Belarus kids[27]	13,127	2-3 weeks	ave 780 max 48k	39-2400	45 thyroid cancer, eventual 50? deaths
Ukraine kids[22]	11,611	2-3 weeks	ave 560 max 33k	28-1600	87 thyroid cancer, eventual 50? deaths
Eben Byers[13]	1	2 years	366,000	300	Horrible bone cancer. Died in 3 years.
Evans radium hi[4]	127	10 years	>80000	80+	Cancers. Hi mortality >200 mSv/d
Dial painters hi[20]	273	10 to 60 yrs	190000-440000	20+	96 bone cancers, 1 below 20
Evans Ra mid[4]	17	10 years	20000-80000	20 to 80	Abnormalities. Nil clinical symptoms.
Dial painters lo[20]	2,110	10 to 60 yrs	200 - 160000	up to 20	Zero bone cancers.
Evans radium lo[4]	59	10 years	up to 20000	max 20	Nil abnormalities
Albert Stevens[18]	1	20 years	61,000	8	Died at age 79 of heart failure.
UPPU Club[25]	26	≈10y	up to 7200	0.03-2	Lower mortality than coworkers.
Taipei Apt hi[2, 8]	1,100	18 years	up to 4000	up to 3	Decrease in cancer, maybe non-rad.
Taipei Apt mid[2, 8]	900	18 years	ave 420	up to .160	Decrease in cancer, maybe non-rad.
Taipei Apt low[2, 8]	8,000	18 years	ave 120	up to .050	Decrease in cancer, maybe non-rad.
Keralans[16]	69,956	10-15 yrs	50-650	.016 to .160	Insignificant decrease in cancer
NRX Clean Up[26]	≈1000	90s jumps	up to 200	up to 150	Insignificant decrease in cancer

Table 1: The Green Table for a repair period of a day. The table indicates that, as long as you stay below about 20 mSv/day, it almost does not matter what the cumulative dose is.

High Dose Radiation Exposures (cont.)

Why 20 mSv/day of ionizing radiation exposure is unlikely cause of cancer

- ▶ 10-50 DNA double strand breaks (DSBs) per cell per day due to normal metabolism
- ▶ 20 mSV/day of ionizing radiation exposure potentially results in 1 additional DSB per day^a
- ▶ Humans thrive with oxygen-based metabolism, repairing DNA breaks caused by reactive oxygen species (ROS) whether induced by metabolism or ionizing radiation